AGRICULTURAL RESEARCH TOWARD INCREASED WHEY UTILIZATION

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The United States Department of Agriculture (USDA) has a long history of research and development activities connected with whey reclamation and utilization. These activities have been sharply increased over the past 10 years when the thrust of global food shortages coupled with strict antipollution regulations forced a reevaluation of previously discarded by-products for food and feed.

The USDA and industrial research efforts have met with some success, as reflected in Table I. These figures, calculated as a percentage of the 1975 production, the first year for which USDA gathered statistics (1, 2), show that the use of condensed and dry whey has been increasing. The slight decline in production of modified whey products such as partially delactosed or partially demineralized whey reflects their decreased use in animal feed in 1976, but this increased again in 1977.

TABLE I.--Production of whey and modified whey products for food and feed

	1976	1977
	Percent of 1975 production	
Condensed	166.7	165.5
Dry	111.1	105.0
Modified dry	94.6	104.0
Lactose	76.0	78.3
Whey solids in wet blends	90.7	84.0

Lactose production in 1976-1977 was constant at about 77 percent of the total production for 1975. The baseline 1975 production figure may reflect the effects of high sucrose prices of 1974 because lactose production reached a peak in March of 1975 and declined steadily to half of the March production by the end of the year (1). Monthly lactose production figures for 1976 and 1977 were constant.

The USDA and state agencies still have an active research program pertaining to whey utilization. Of 83 projects that were initiated in January 1974 or later, Agricultural Research is responsible for 19, the Cooperative States Research Service for 45, and the State Agricultural Experiment Stations for 19. There are also 39 projects relating to lactose; however, this figure is high because some of the projects listed for whey were cross-indexed under lactose.

Whey research projects currently underway at the Eastern Regional Research Center (ERRC) in the Dairy and Engineering and Development Laboratories are as follows:

1. Derivatization of lactobionic acid.
2. Oxidation of lactose to acidic disaccharide derivatives.
3. Innovative whey processing and use.
4. Whey based cultured products.
5. Prevention of flavor deterioration in stored whey protein concentrates.
6. Factors affecting the film properties of whey foams.
7. Whey components as humectants for intermediate moisture foods.
8. Nutritious beverage powders formulated from whey solids and vegetable proteins and/or fats.

This research is conducted with 16SY and some support help. The present paper reports progress made under these work units.

LACTOSE UTILIZATION RESEARCH

The extensive lactose utilization research program at ERRC was discussed in detail at the 1976 Whey Products Conference (3), with special emphasis on lactose derivatives. However, increasing the utilization of lactose still remains a major unsolved problem in the dairy industry.

Many sugar acids can form water soluble metal complexes because of the ability of the carboxyl and hydroxyl groups to bind cations in ring form by means of coordinate and covalent bonds (4). A knowledge of the specific conditions under which such complexing is most effective could lead to new outlets for these products (5).

An example of such a sugar acid is lactobionic acid, which may be prepared readily from lactose under mild oxidizing conditions (6). This product can be used in alkaline solution as a chelating agent for heavy metals, such as iron, under conditions where EDTA is not effective. However, gluconic acid, a sequestrant familiar to the soft drink industry among others, is about twice as effective as lactobionic acid for this purpose (7).

Calcium, cupric and ferric salts of lactobionic acid have been prepared (8). These lactobionates may have potential as a means of supplying heavy metals to plants; evaluations are still underway.

To date, it has been found that esters formed from lactobionic acid are not stable. However, lactobionic acid may be cyclized by dehydration to form a lactone (9); as a result, a reactive chemical has been derived from lactose. For example, the lactone is reactive with amines to form stable amides (10). An extensive examination of the characteristics of nitrogenous derivatives such as N-dodecyl-lactobionamide or 1,6 dilactobionamido hexane is presently underway (8). No antimicrobial activity (11) or other special use for any of these derivatives has been identified as yet.

α-Lactose may be isomerized to lactulose in which the glucose moiety of lactose has been converted to fructose (12). It was thought that lactulose might possess sweetness, humectant, and solubility properties which would make it useful in food applications (13).

For testing, lactulose was prepared as follows (14):

1. Stir lactose in saturated $Ca(OH)_2$ solution 48 hours at room temperature.

2. Remove residual lactose by concentration, crystallization.

3. Remove residual calcium ion by IR 120 ion-exchange resin.

4. Remove glucose, galactose, and color with charcoal.

Following this procedure, lactulose may be recovered in 15 percent yield as a 70 percent syrup. This syrup has shown no tendency to crystallize or develop color even after 3 years of storage at 4 C.

Extensive organoleptic evaluations were conducted to gain some knowledge of the sweetness of lactulose when compared to sucrose. The curve in Figure 1 describes the sweetness of lactulose, equilibrated for 16 hours before being tasted, over the range of concentration 5-35 percent (W/V) relative to sucrose. This means, for example, that a 10 percent solution of lactulose has sweetness equal to about a 5 percent sucrose solution. Although not shown, a solution concentration of 13.5 percent lactose would be necessary for equal sweetness (15).

Lactulose also has potential as a humectant. Data indicate that lactulose is more effective than sucrose in controlling water activity. To obtain an a_w of 0.85, only 47.4 percent lactulose solution (52.6 percent water) is required compared to a 67.3 percent sucrose solution (32.7 percent water). To obtain an a_w of 0.90, 30 percent lactulose solution (69.3 percent water) is required compared to a 58 percent sucrose solution (41.5 percent water). This effect was apparent at all concentrations examined (13).

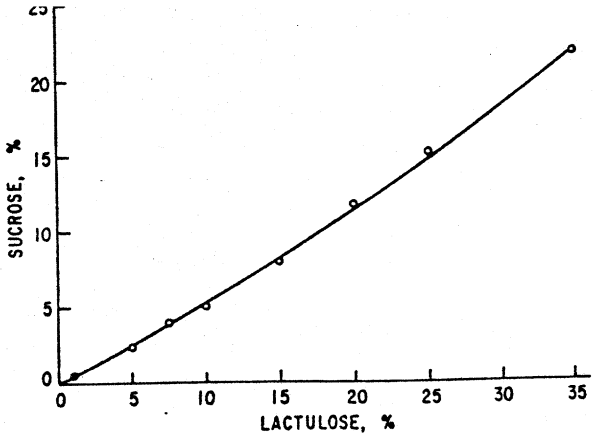

Figure 1.--Plot of lactulose concentration versus sucrose concentration for equal sweetness.

Some bread baking studies have been carried out with lactulose. Straight dough breads made with lactose or lactulose in a reduced sucrose and shortening formulation produced more tender breads as measured by compression; volume and taste panel scores were no different than controls, however. Sponge and dough breads containing lactulose or lactose were equivalent to controls in all respects (16).

HYDROLYZED LACTOSE STUDIES

Some potential uses for whey which had been treated with lactase enzyme (β-galactosidase) to hydrolyze lactose to glucose and galactose were described at the 1974 Whey Products Conference (17). Some advantages of lactase treatment for product applications include reduced lactose content, prevention of lactose crystallization, increased solubility, increased sweetness, and more rapidly fermentable sugars.

Clear, nearly colorless syrups may be prepared from lactose either by enzymatic treatment or by an older method, hydrolysis with hydrochloric acid and heat. A flow sheet describing the preparation of enzyme processed syrups is shown in Figure 2.

A suspension of either 0.1 percent purified lactase (W/V) or 0.2 percent crude lactase was added to 3 liters of 0.584 M lactose dissolved in distilled water and brought to pH 6.4 with 0.01 M phosphate buffer. After 6 hours at 30 C, the enzyme was inactivated by heating to 75 C; hydrolysis was over 90 percent. The solution was decolorized with 1 percent charcoal, after which the filtrate was demineralized by being passed over Dowex 50W-X8 in the H^+ form. Filtrates at pH 2.2 were then passed over Dowex 2-X8 in the OH^- form, after which the eluates were adjusted to pH 5.4 - 5.6, then condensed in vacuo to 60-66 percent total solids (TS) at 60-70 C (18).

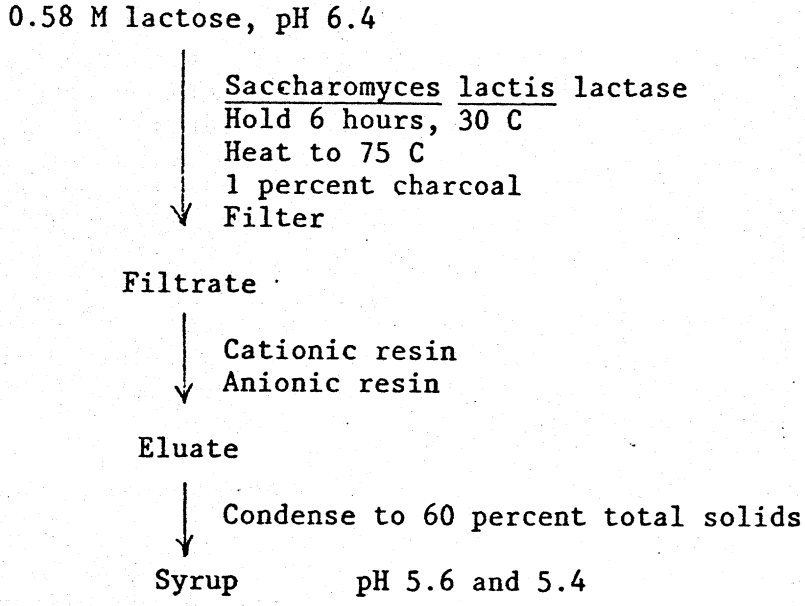

Figure 2.--Flow sheet for the preparation of syrups by enzymatic hydrolysis of lactose.

The hydrolyzed lactose syrups were as sweet as sucrose syrups above 50 percent TS but less sweet at lower levels (Figure 3). Although increasing lactose hydrolysis from 75 to 95 percent increased sweetness, observed differences were very small.

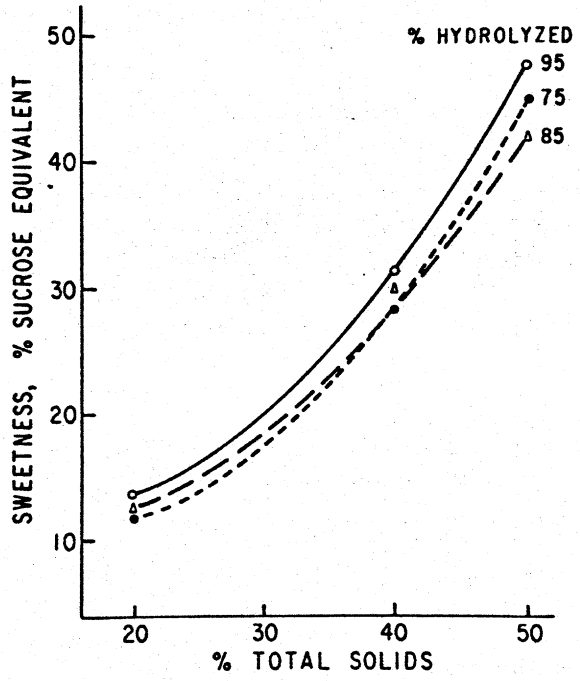

Figure 3.--Effect of extent of hydrolysis of lactose in syrups on their sweetness relative to sucrose.

The degree of hydrolysis affected the crystallization rate. Crystallization occurred more rapidly in syrups with 95 percent hydrolyzed lactose irrespective of the TS content (Table II). Analysis of the crystals formed in the 95 percent hydrolyzed syrups showed them to be primarily galactose; this could be expected because the solubility limit of galactose is 32.1 percent, whereas that of glucose is 50.8 percent (19). Syrups of 60 percent TS, low enough to resist crystallization, formed mold in less than a month.

Crystallization could be retarded by pasteurizing the syrup and sealing the container (Table III); this also prevented microbiological deterioration. Best stability was observed in pasteurized syrups with 75 percent hydrolyzed lactose and 63-66 percent TS (18).

TABLE II.--Crystallization rates of unheated syrups made from lactose

Percent enzymatic hydrolysis	Days to crystallization at 23 C (Total solids, percent)		
	60 percent	63 percent	66 percent
95	7	2	2
85	>40[1]	16	4
75	>50[1]	>250	>250

[1]Mold formed in 28 days.

TABLE III.--Crystallization rates of enzyme processed syrups containing 60 percent total solids

Percent hydrolysis	Weeks to crystallize at 23 C	
	Unheated	Heated to 75 C and sealed
95	<1	6-12
92	1	15>47

Because of their sweetness at high solids levels and humectant properties, these syrups could find application in confections. To test humectant properties, milk caramels were selected as the test candy (20) and formulated as in Table IV. Syrups prepared from both hydrolyzed lactose and lactase treated sweet whey with 90 percent of its lactose hydrolyzed were tested. When whey was used as the humectant, the amount of sweetened condensed whole milk in the formulation was reduced because of the protein in the whey.

Butterfat and sucrose were added to levels present in the other two formulations. Both humectants were added at the 5 percent level. All caramels with added humectant showed less crystallization at the surfaces of the rolled layers and less shrinkage during storage at 23 C and 40 percent relative humidity for 2½ months than did the control.

Evaluations of the caramels prepared with 5 percent humectant are listed in Table V. After 6 months storage, the control showed a significantly greater moisture loss than either of the caramels containing added humectant. Samples containing the hydrolyzed lactose syrups showed highest flavor score on a 9 point hedonic scale (21). Although there was no difference in liking for the three caramels in the first test, the second test showed that both the control and the product containing lactase-treated whey were significantly less well-liked. The sample containing lactase-treated whey also showed a significantly greater hot spread than the other two samples. There was little difference in initial moisture, however.

TABLE IV.--Caramel formulations

Ingredient	Control	Hydrolyzed lactose syrup	Hydrolyzed lactose sweet whey
Sweetened condensed whole milk	1000	1000	825
42DE corn syrup	600	600	600
Sucrose	200	200	273
Hard fat (Paramount C)	100	100	100
Syrup or whey	-	130	160
Butterfat	-	-	16
Salt	4	4	4
Lecithin	3	3	3
Vanilla extract	8	8	8

The availability of hydrolyzed lactose whey as a spin-off of the ERRC cheese research program prompted an evaluation of this by-product as an ingredient in ice cream, since ice cream and other frozen desserts represent a logical outlet for whey (22). Formulations evaluated are listed in Table VI. Two levels of lactose hydrolysis were examined. With increasing levels of whey solids, both the milk solids not fat and the sucrose level could be

reduced in the formulation. This reduction resulted in a decrease in protein with increasing whey solids, amounting to a 20 percent decrease in the formulation containing 11 percent whey solids and a 30 percent increase in ash content. This work was undertaken prior to the dropping of the proposed ice cream standards; the only formulation listed in Table VI which would meet present standards is that containing 2.75 percent whey solids.

TABLE V.--Evaluation of caramels made with 5 percent humectant

Evaluation	Control	Hydrolyzed syrup	Hydrolyzed sweet whey
Caramel moisture, percent	9.22	9.07	8.89
Hot spread, cm^2/g	1.08[2]	1.02[2]	1.41[1]
Taste hedonic panel score[4]	7.21[1] 7.12[2],[3]	7.75[1] 7.93[1]	7.21[1] 6.43[3]
Percent moisture loss[4] 6 months, 23 C, 40 percent RH	1.40[1]	1.02[2]	0.57[3]

[4]Common numbers - not significantly different across at the 5 percent confidence level.

TABLE VI.--Ice cream formulation[1]

	Percent	
Percent whey solids[2]	Milk solids not fat	Sucrose
0.00	11.0	15.00
2.75	9.5	13.75
5.50	8.0	12.50
8.25	6.5	11.25
11.00	5.0	10.00

[1]12 percent fat and 0.14 percent stabilizer.

[2]67 percent or 79 percent hydrolyzed lactose.

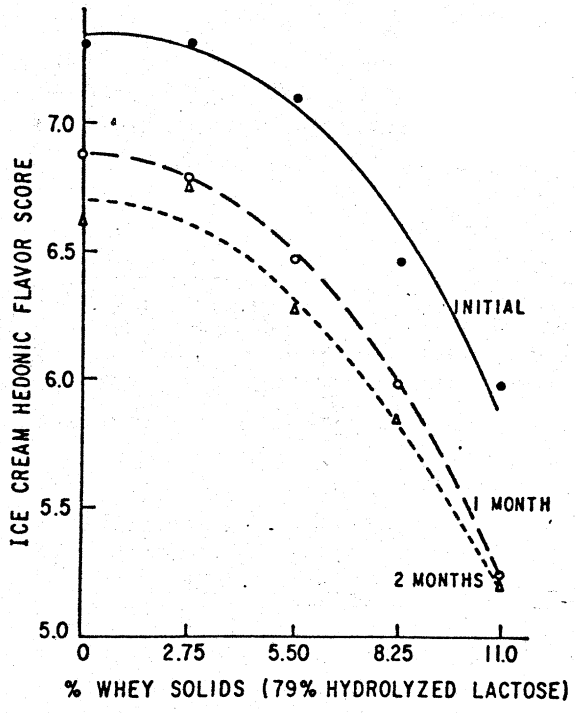

Figure 4.--Effect of concentration of whey solids on the hedonic flavor score of ice cream.

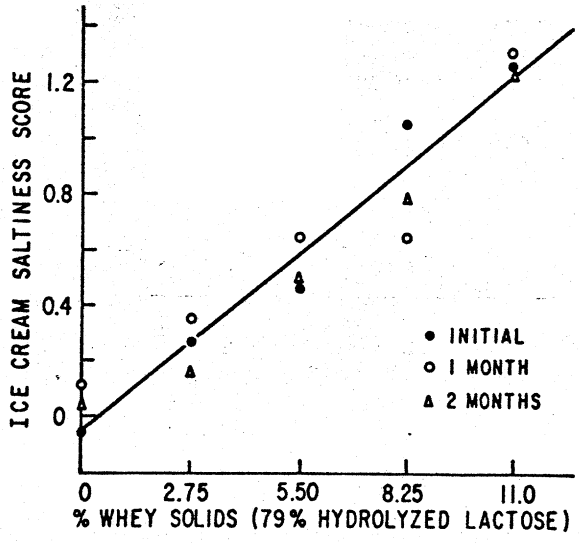

Figure 5.--Effect of concentration of whey solids on saltiness score of ice cream.

The hedonic flavor scores (21) given the ice creams decreased with increasing levels of whey solids (Figure 4). There was also a reduction in flavor score between the initial tasting and the tasting after one month of storage; all scores were above 5, however, representing some liking for the product, even at highest whey levels.

The decline in flavor score with increasing whey solids could be attributed to excess saltiness, as shown in Figure 5. Judges were asked specifically to score the ice creams for saltiness. Saltiness score increased with increasing levels of whey solids and became significantly different from the control in the samples containing 5.5 percent whey solids or more.

DEMINERALIZATION

Saltiness of wheys in general has frequently been a barrier to whey utilization, especially in the case of whey permeates, the by-products of ultrafiltration operations. With the appearance on the market of ion exchange resins thermally regenerable with hot water instead of with acids and bases, thereby reducing operating costs (23), their potential for demineralization of whey permeates was immediately apparent.

The effects of demineralization of the ultrafiltrate on the yield of lactose by crystallization were evaluated according to the treatment scheme in Table VII (24). The ultrafiltrate is first passed over a Duolite column to obviate possible irreversible fouling of the Sirotherm resins by residual protein. Riboflavin was also presumed to be removed in this step, since the permeate was completely decolorized. Because Sirotherm resins have been used mainly to treat brackish water (25) and, in water treatment, the most economical procedure was to remove the divalent cations and monovalent cations in successive steps, this sequence was followed for treatment of the permeate. At the end of the treatment sequence, 76 percent of the calcium, 90 percent of the magnesium, and virtually all of the sodium and potassium ions were removed. Calcium and magnesium were removed because preliminary experiments with simulated ultrafiltrate showed that these cations reduced lactose yield by about 14 percent.

The yield of α-lactose monohydrate, crystallized from a 50 percent total solids solution, was significantly greater from the completely deionized solution than from ultrafiltrate from which only divalent cations had been removed or from ultrafiltrate that had not been passed over the Sirotherm resins (Table VIII). Lactose crystallized from solutions from which calcium and magnesium or all four cations had been removed met all the criteria for edible lactose (26). Explanations for the differences in yields must await more detailed studies of the numerous factors involved in lactose crystallization.

FLAVOR

Whey is an excellent source of vitamin B_2, riboflavin, containing from 2 to 2.2 mg per 100 g of solids (27). Riboflavin is implicated in the development of light-induced off-flavors in milk and dairy products (28). Lumichrome, the structure of which is shown in Figure 6, along with the mass spectrum, has been clearly established to be a major photodegradation product of riboflavin in milk exposed to sunlight; a method has been developed for its isolation (29). Traces of this compound may be detected just prior to the onset of off-flavor; whole milk has a strong off-flavor when only about

1 percent of the riboflavin has degraded. Lumichrome also forms and can be detected after only 1 hour of exposure to fluorescent light. Lumichrome has been found in commercially spray dried whey protein concentrates. This isolation method may offer an objective means of identifying samples that have undergone photochemical reactions as the result of excessive exposure to light and may be off-flavored as a result.

TABLE VII.--Treatment scheme for the demineralizatin of cheddar whey ultrafiltrate

Resin[1]	Purpose
Duolite S-761	Removes protein
Sirotherm TR-10 ($\bar{X}o = 0.5$)	Removes Ca^{++}, Mg^{++}
Duolite C-20 (Na)	Softening step
Sirotherm TR-10 ($\bar{X}o = 0.1$)}	Removes monovalent ions (Na^{+}, K^{+})
}	
Sirotherm TR-20 ($\bar{X}o = 0.1$)}	

[1]Reference to brand or firm name does not constitute endorsement by the U.S. Department of Agriculture over others of a similar nature not mentioned.

TABLE VIII.--Yields of α-lactose monohydrate from treated ultrafiltrate and a control

Source of lactose	Percent yield
α-Lactose monohydrate control	67.2 ± 0.5
Duolite S-761 treated ultrafiltrate	43.5 ± 1.8
Ca^{++} & Mg^{++}-free ultrafiltrate	39.6 ± 0.7
Deionized ultrafiltrate	56.4 ± 0.8

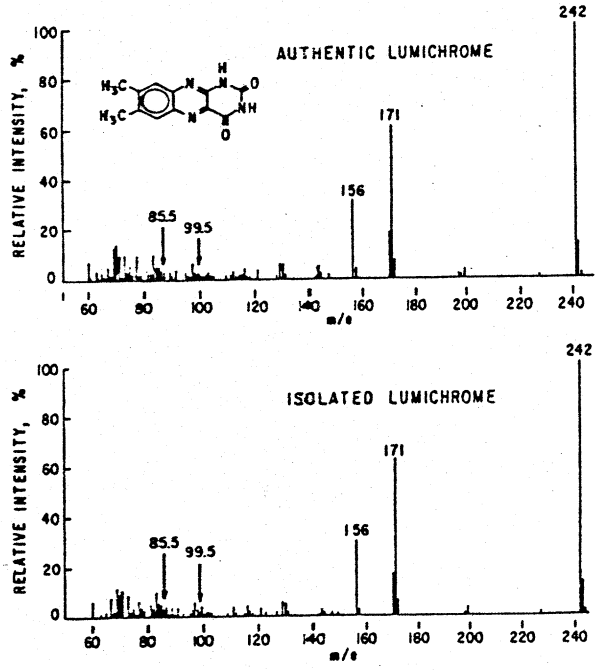

Figure 6.--Comparison of mass spectra of lumichrome isolated from skim milk exposed to sunlight and the authentic compound.

WHEY FERMENTATION

A major problem in using whey as a fermentation substrate to date has been that relatively few organisms can ferment lactose, Kluyveromyces fragilis being the most efficient (30). In a commercial application for whey wine production, dextrose was added to the fermentation medium so that a typical wine yeast, Saccharomyces cerevisiae could be used (31). This means that the lactose was left intact.

The availability of lactase-treated acid whey at ERRC led to an investigation of alcohol production by S. cerevisiae and K. fragilis (30). Complete fermentation of the sugar and maximum alcohol production by K. fragilis required 120 hours at 30 C in lactase-treated acid whey compared to 72 hours in the control (Figure 7). This was due to a diauxic fermentation pattern in the lactase-treated whey, with glucose being fermented before galactose. S. cerevisiae produced alcohol from glucose more rapidly than did K. fragilis but fermented galactose only when pregrown on galactose.

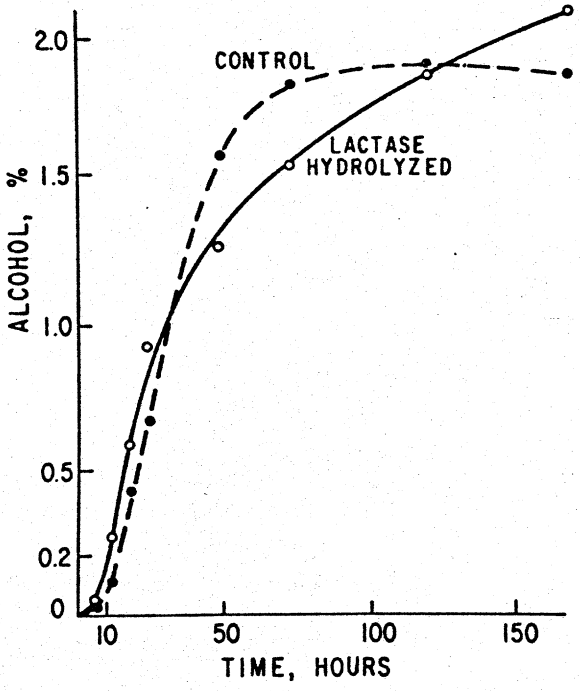

Figure 7.--Alcohol production by glucose-pregrown Kluyveromyces fragilis in control and lactase hydrolyzed acid wheys.

A whey permeate is better than acid whey as a starting material because the presence of protein generally causes problems with clarity in the manufacture of any alcoholic beverage (32). Alcohol production from acid whey permeates with K. fragilis and S. cerevisiae is shown in Figure 8 (33). With S. cerevisiae, alcohol yields of 6.5 percent were obtained in lactase-treated permeates condensed to 30-35 percent total solids prior to inoculation. The maximum yield obtained with K. fragilis was 4.5 percent at 20 percent total solids in the lactase-treated permeate and 3.7 percent at 10 percent total solids in the control permeate. Although S. cerevisiae efficiently converted the glucose present to alcohol, galactose, comprising about half of the available carbohydrate, was not utilized at all. This means that, even though the alcohol yield was higher, the process was wasteful in that a good proportion of substrate was not utilized. It was concluded that, although lactose prehydrolysis was advantageous in that microbial species unable to ferment lactose could be utilized, a commercially feasible process must consider diauxic problems and have an efficient means of rapidly converting galactose to alcohol.

With increasing use of polysaccharide gums as stabilizers in engineered foods, the possibilities of gum synthesis in whey based media have been examined at ERRC (34). Experiments were conducted with Xanthomonas campestris to study the carbohydrate utilization patterns in different whey types and the amounts of gum produced. β-Galactosidase (lactase), assayed in cells grown in different media, proved to be part of the constitutive system, since the enzyme was produced in low levels in glucose media.

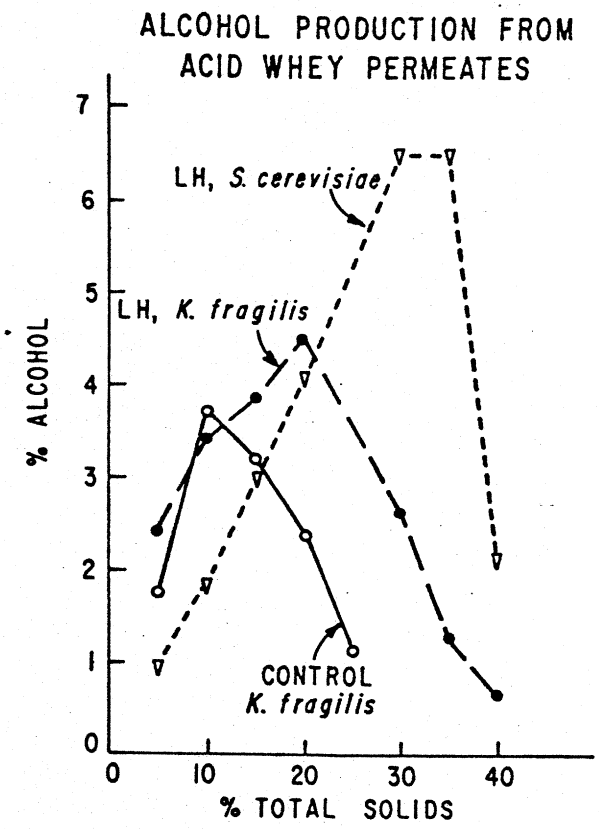

Figure 8.--Alcohol yields obtained by fermentation of lactase hydrolyzed whey permeate and whey permeate by Saccharomyces cerevisiae and Kluyveromyces fragilis.

It was necessary to induce and stabilize mutant strains to convert lactose to microbial polysaccharides; of 32 mutant strains cultured, only 8 survived after two subculturings. They could be maintained on lactose agar media but grew poorly in whey permeate.

Gums could be produced in lactase-treated acid whey permeate. Good gum production was obtained when the permeate was diluted to 5 percent total sugar calculated as glucose or diluted further to a minimum of 2.5 percent total sugar and adjusted to pH 7.0 with potassium hydroxide. This process was carried out under slightly alkaline conditions; the carbohydrate substrate was 96 percent metabolized and 55 percent was converted to gum. Evidence also showed that glucose and galactose were utilized simultaneously. Highest viscosity levels were observed 8-10 days after inoculation. The available carbohydrate was 50 percent depleted in 4 days; about 50 percent of the available protein and lactate had disappeared after 3 days. The gum was isolated and purified by solvent and salt fractionation; the pyruvate content proved to be 3.2 percent. These gums are undergoing further tests at the present time.

Since 1973, considerable time has been spent on research and development activities related to the production and properties of whey soy drink mix, a nutritious beverage powder specifically designed as a dietary supplement for preschool children receiving inadequate protein (35). To date, the U.S. Department of Agriculture has purchased over 10 million kilograms of whey soy drink mix since distribution first began in 1974 (36). This year, it is planned to ship about 3 million kilograms for use in child feeding programs in Pakistan, Bolivia, Chile, and Haiti, even though there is a worldwide surplus of nonfat dry milk.

Peanut based products often have been proposed and used in overseas programs because peanuts are a surplus commodity in the United States; in addition they are a familiar crop in many of the developing countries where Food-for-Peace programs operate (37). Based on experience gained in the work with whey soy drink mix, a whey peanut blend has been prepared as in the formulation in Table IX (38). The product, containing 50 percent sweet whey solids, is intended for beverage use after reconstitution with water. The reconstituted whey peanut blend has a more acceptable flavor than whey soy drink mix has; its hedonic rating was 6.1, significantly higher than the 4.9 received by whey soy drink mix.

TABLE IX.--Formulation of whey peanut blend

Ingredient	Percent
Sweet whey solids	50.0
Defatted peanut flour	24.6
Soybean oil	20.0
Corn syrup solids	5.4

Unfortunately, this product in its present stage of development lacks the storage stability of whey soy drink mix. Peroxides develop rapidly in the whey peanut blend during storage (Table X); even at a moderate storage temperature, this development could be correlated with detection of oxidized flavor by trained judges after only 53 days of storage. Such a serious storage stability problem renders this product unacceptable for use in food donation programs at present, even though with a PER of 2.0, it has the nutritional quality required. This problem is still being investigated.

TABLE X.--Peroxide values (meq O_2/kg fat) of whey peanut blend stored for varying lengths of time

	Initial	Storage time - days					
		25	53	81	109	137	165
Control N_2 pack, stored -18 C	10.1	9.3	8.4	8.3	11.3	14.2	15.2
Air pack, stored 20 C	-	17.7	27.7	30.9	37.1	45.9	55.4
Air pack, stored 37 C	-	19.4	32.0	38.0	57.4	74.6	82.1

WHEY PROTEIN CONCENTRATES

The ERRC whey research effort also has been expended on the question of why an aqueous dispersion of a whey protein concentrate (WPC), when whipped to a foam, collapses when heat is applied. A 20 percent total solids dispersion of WPC carries the sucrose and flour very well when whipped into an angel food cake batter; when placed in the oven, the batter rises until, after about 12-15 minutes of baking, total collapse occurs (39).

Physical properties of the angel food batters are listed in Table XI. A 14 percent WPC batter is shown for comparison because the TS of liquid egg white amounted to 14 percent; in practice, a 20 percent WPC batter was used. The viscosities were quite different; however, with increased viscosity, foam stability should increase. Foam densities and surface tension of the 20 percent WPC batter and the egg white batter proved to be close.

TABLE XI.--Physical properties of aqueous dispersions of whey protein concentrate compared to egg white at pH 4.7 with 44 percent sucrose added

Sample	Liquid density g/cc	Foam density g/cc	Apparent viscosity cp	Surface tension dynes/cm
WPC (14 percent TS)	1.229	0.19	34.2	48.6
WPC (20 percent TS)	1.242	0.27	79.3	49.1
Egg white (14 percent TS)	1.226	0.24	25.3	52.6

TABLE XII.--Effect of whipping for 10 minutes on solubility of 1.5 percent protein solutions in 0.1 percent sodium chloride at pH 4.7

Protein	Percent insoluble after whipping
β-Lactoglobulin	5.7
α-Lactalbumin	2.3
Bovine serum albumin	0
Mixed whey proteins	0
Ovalbumin	3.7
Egg white	11.1

Egg white is believed to form a stable foam because of the tendency of ovalbumin, the major egg protein, to undergo a configurational change at an air-water interface, resulting in solubility loss (40, 41). The tendency of solutions of the whey proteins to insolubilize when whipped was examined (Table XII). No insolubilization of bovine serum albumin or of the mixed whey protein dispersion occurred. β-Lactoglobulin, the principal whey protein, was more sensitive to surface denaturation than ovalbumin was under these conditions. The mixed whey proteins must either contain factors or exist in a conformation which stabilizes the system against surface denaturation.

Prolonged whipping leads to the formation of smaller bubbles; the resultant increase in surface area means that there are more air-water interfaces available from which liquid can drain, until at some time the bubble becomes so weak that it collapses.

Bubble thinning and bubble collapse must be related in some way to the film forming properties of the proteins. Knowledge of the conformation of a protein at the air-water interface may be gained by examining the conformation of the protein when it has been spread in a thin film on the surface of a solvent and then compressed. A method has been devised whereby the film is spread by a Langmuir film balance, picked up at the desired compression on a quartz surface and examined for conformation by circular dichroism spectroscopy and UV spectroscopy (42). The curves in Figure 9 are those of polymethylglutamate and polyalanine which were used as model proteins in the film balance. The plateaus on two of the curves represent the points where the protein is no longer a monolayer. Analysis by circular dichroism showed the two s-shaped curves to be α-helices; the smooth curve is that of polymethylglutamate in the β-conformation.

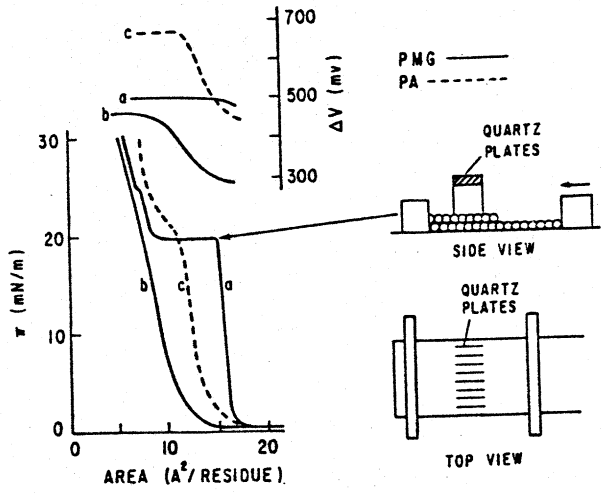

Figure 9.--Pressure (π) - area and surface potential (DV) isotherms of polypeptide monolayers. Polymethyl-glutamate spread from (a) chloroform-dichloro-acetic acid (99:1 vol); (b) pyridine-chloroform (98:2); (c) polyalanine spread from chloroform-dichloroacetic acid (99:1).

Because this method is still being developed, no data for the whey proteins are yet available. However, increased knowledge of the film forming properties of the whey proteins should shed some light on their behavior as a foam.

CONCLUSION

From the progress reported here, it is evident that the potential for using whey in its various forms remains strong. Many products now available commercially contain large quantities of whey, benefiting both the processor and the consumer. The greatest challenge for the future lies in exploring those options for whey utilization that do not compete directly with skimmilk powder. ERRC research scientists are interested in nutrition, nutrient stability and food safety and quality research programs, and they remain available for consultation concerning industrial problems.

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